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Relationship between substorm activity and magnetic disturbances in two polar caps

Sonya Lyatskaya,[1] W. Lyatsky,[2] and G. V. Khazanov[2]

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[1] We examined the effect of magnetic disturbances in two polar caps on the generation of magnetospheric substorms. For this purpose we investigated the correlation between the *AL* index (showing substorm activity in the Northern hemisphere) and two geomagnetic activity indices, the Polar Cap (*PC*) index and Polar Magnetic (*PM*) index showing the magnetic disturbances in the Northern and Southern polar caps. For the analysis we used the data for four years when geomagnetic activity indices were available in both hemispheres. We obtained an unexpected yet important result: while in northern winter the correlation between *AL* index and northern *PC*/*PM* indices is very good, in northern summer the *AL* index correlates much better with southern *PC*/*PM* indices. Thus, substorm activity in summer months correlates much better with geomagnetic activity not in the nearby polar cap but in the opposite polar cap. This effect may be caused by the interhemispheric field-aligned currents flowing from the summer high-latitude ionosphere and closing through the ionosphere in the opposite auroral zone. An interesting feature of these interhemispheric currents is that they are directed opposite to the substorm field-aligned currents in the summer hemisphere but along the substorm field-aligned currents in the winter hemisphere. This leads to decreasing the total field-aligned currents and their contribution to magnetic disturbances in the summer hemisphere but increasing these currents and related magnetic disturbances in winter hemisphere, which explains the experimental results obtained in our study. **Citation:** Lyatskaya, S., W. Lyatsky, and G. V. Khazanov (2008), Relationship between substorm activity and magnetic disturbances in two polar caps, *Geophys. Res. Lett.*, *35*, L20104, doi:10.1029/2008GL035187.

1. Introduction

[2] The relationship between geomagnetic disturbances, electric fields, field-aligned currents, and related events in two high-latitude ionospheres is an important field of research [e.g., *Papitashvili and Rich*, 2002; *Engebretson et al.*, 2003; *Ridley*, 2007; *Ohtani et al.*, 2005a, 2005b]. It is well known that the field-aligned currents (FAC) increase in dayside high-latitude ionosphere and show a significant seasonal variation which may be explained as a result of increasing ionospheric conductance in dayside sunlit conditions [e.g., *Fujii et al.*, 1981; *Papitashvili and Rich*, 2002; *Ridley*, 2007; *Ohtani et al.*, 2005a, 2005b]. The situation in the nightside sector is more complicated. Some researchers [*Fujii et al.*, 1981; *Christiansen et al.*, 2002; *Wang et al.*, 2005] reported that nightside FAC, in contrast to dayside FAC, show no significant variation with season and solar radiation, while other researchers [*Ohtani et al.*, 2005a, 2005b] reported that nightside FAC in the winter ionosphere are even more intense than in summer ionosphere; similarly *Østgaard et al.* [2005] found that FAC in near-midnight sector are stronger in the winter than in the summer.

[3] Thus, the experimental results show that nightside FAC, in contrast to dayside FAC, are either independent of season or even increase in winter months. This feature in the behavior of nightside FAC is consistent with the observations of nightside auroras which show the suppression in sunlit ionosphere and in summer months [*Newell et al.*, 1996; *Liou et al.*, 2001], and electron beams, accelerated upward out of the auroral ionosphere [*Cattell et al.*, 2004], which are observed predominantly in dark ionosphere. Preferences for the dark, unilluminated ionosphere can also be found for the occurrence of many other events [*Ohtani et al.*, 2005a]. The cause for this anomalous behavior of field-aligned currents, auroras, and accelerated particle fluxes is not quite clear [e.g., *Hurtaud et al.*, 2007].

[4] The purpose of this paper is to examine the relationship between substorm activity and magnetic disturbances in two polar caps.

2. Data and Method

[5] We examined the correlation between substorm activity, which is described by the auroral electrojet *AL* index, and two indices of geomagnetic activity, measuring geomagnetic activity in two (northern and southern) polar caps: the polar cap *PC* index [*Troshichev et al.*, 2006] and a recently introduced polar magnetic *PM* index [*Lyatsky and Khazanov*, 2008]. The auroral electrojet *AL* index is derived from geomagnetic variations from selected observatories along the northern auroral zone only; this index shows the westward auroral electrojet in the northern auroral zone, which is an important feature of substorm activity. While computing the *AL* index, a magnetic effect of all quiet-time currents, including quiet-time interhemispheric currents, is subtracted. However, during magnetic disturbances the Region 1 field-aligned currents and interhemispheric currents increase and may provide a significant contribution to the seasonal effect in the geomagnetic disturbances at high latitudes. The polar cap *PC* index measures the magnitude of the equivalent transpolar electrojet in a specific (predominant) direction [*Troshichev et al.*, 2006] at two near-pole geomagnetic observatories: Thule (Greenland) and Vostok (Antarctica). The *PC* index may be positive, negative, and equal to zero (when the equivalent transpolar electrojet is

[1]Department of Physics, Alabama A&M University, Normal, Alabama, USA.
[2]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

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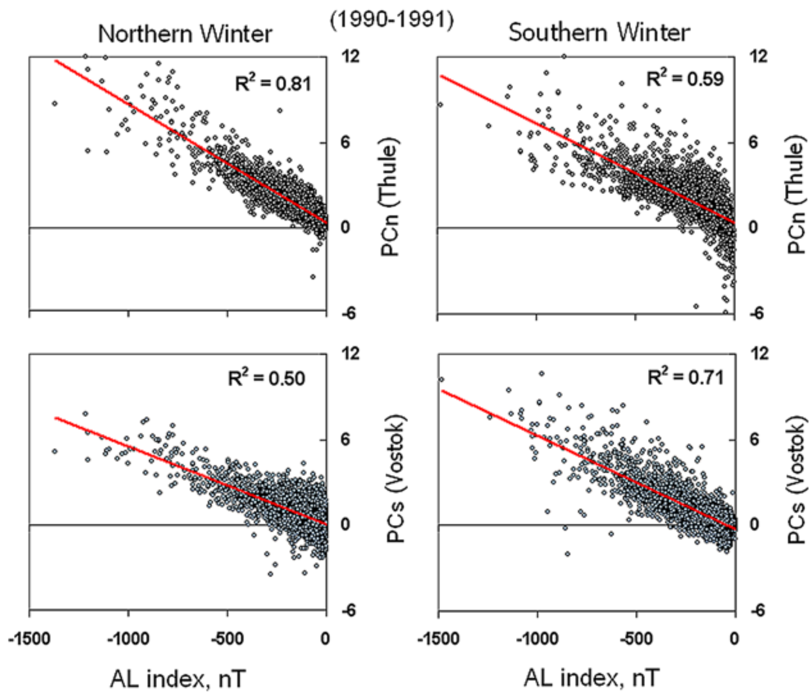

Figure 1. Correlation of *AL* index with *PCn* and *PCs* polar cap indices, computed for 1990–1991 from data from the northern and southern near-pole geomagnetic observatories, respectively, related to (left) winter months in the northern hemisphere and (right) winter months in the southern hemisphere. The squared correlation coefficients are shown.

perpendicular to its predominant direction). It was originally suggested that this index measures the cross-polar-cap convection flow, but later it was shown [e.g., *Huang*, 2005; *Lyatsky et al.*, 2006, 2007] that the contribution to the transpolar electrojet from substorm currents may be comparable or even exceed the contribution from ionospheric currents. Nevertheless, this index shows relatively high correlation with solar wind parameters, and its important advantage is that it may be available in two hemispheres.

[6] The recently developed polar magnetic (*PM*) index is computed from the same two near-pole geomagnetic observatories (Thule and Vostok) in two hemispheres; however, another approach was used for its calculation [*Lyatsky and Khazanov*, 2008]. In distinction from the *PC* index, the *PM* index (1) accounts for the contribution from the transpolar electrojet even when the latter is significantly different from the predominant direction, and (2) while its computing, the effect on the Interplanetary Magnetic Field (IMF) *By*, responsible for the generation of a single current vortex in the polar cap region, was reduced. An additional distinction of the *PM* index is that it is always positive. As a result, the new *PM* index shows much better correlation with both solar wind parameters and many other disturbances in Geospace environment [*Lyatsky and Khazanov*, 2008], and similarly to the *PC* index, it may also be computed in two hemispheres.

[7] For the analysis, we used the data for four years, 1990–1991 and 1997–1998. For the first time interval, only the *AL* index and *PC* indices in two hemispheres were available; for the second time interval, the *AL* index and both *PC* and *PM* indices in two hemispheres were available.

[8] We took the auroral electrojet *AL* index from the web site of WDC in Kyoto, Japan, at http://swdcwww.kugi.kyoto-u.ac.jp. The *PC* index in the northern hemisphere (*PCn* index) is provided by the WDC, Danish Meteorological Institute and it is available at http://www.ukssdc.ac.uk. The *PC* index in the southern hemisphere (PC_S index) is provided by the Arctic and Antarctic Institute in Russia; this index is available for some years at http://www.wdcb.ru/stp/data/geomagni.ind/pc. We used for the analysis the hourly values of these indices.

3. Main Results

[9] For the analysis, we used the cross-correlation between hourly values of the *AL* index and the *PC* and *PM* indices in two hemispheres. Figure 1 shows the results of the correlation of the *AL* index with *PCn* index in the northern hemisphere and *PCs* index in the southern hemisphere for three northern winter months (November, December, and January) and three southern winter months (May, June, and July) for 1990–1991. We remind that the *PCn* and *PCs* indices were computed from geomagnetic data from the northern (Thule) and southern (Vostok) geomagnetic observatories, respectively.

[10] The left plots of Figure 1 show the correlation of *PCn* and *PCs* indices with *AL* index for the northern winter. One can see that the correlation of *AL* index with the northern *PCn* index is much better (the squared correlation coefficient $R^2 \approx 0.81$) than that with the southern *PCs* index ($R^2 \approx 0.5$), which is quite expected. However, for the southern winter, as shown on the two right plots of Figure 1, the results are in contrast unexpected and even

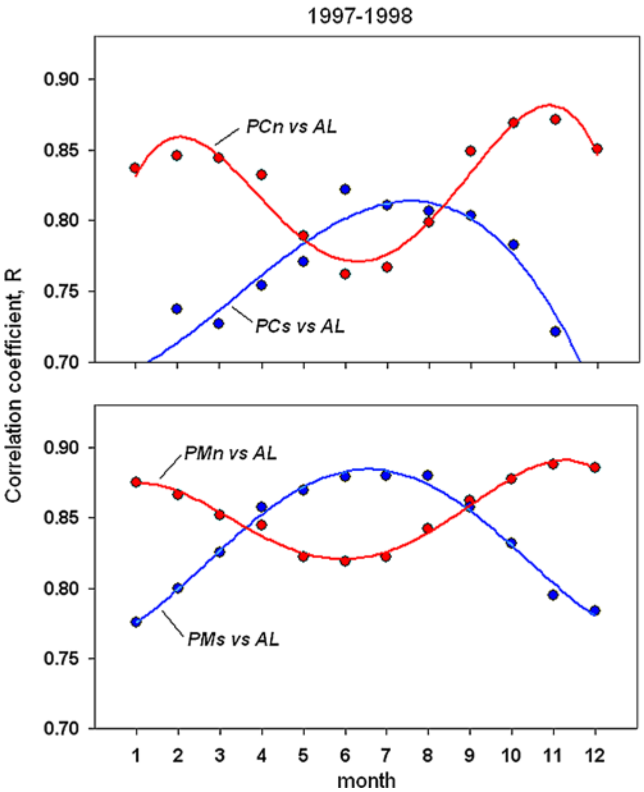

Figure 2. Seasonal variation of the linear correlation coefficients, R, for the correlation of *AL* index (top) with polar cap *PCn* and *PCs* indices and (bottom) with polar magnetic *PMn* and *PMs* indices for 1997–1998. The correlation of *AL* index with northern *PCn* and *PMn* indices is shown in red; the correlation of *AL* index with southern *PCs* and *PMs* indices is shown in blue. Each dot in this figure includes ~1445 measurements. The curves are the fourth-order polynomial fit to the data.

puzzling: In this case, the correlation of *AL* index with the northern *PCn* index appears much worse ($R^2 \approx 0.59$) than that with the southern *PCs* index ($R^2 \approx 0.71$).

[11] Figure 2 shows the correlation between *AL* index and two (*PC* and *PM*) indices, each of them was computed in two polar caps. The linear correlation coefficients, R, in Figure 2 were computed for different months for two years (1997–1998). The top plot of Figure 2 shows the linear correlation coefficients for the correlation of *AL* index with the northern *PCn* and southern *PCs* indices, while the bottom plots show the linear correlation coefficients for the correlation of *AL* index with northern *PMn* and southern *PMs* indices.

[12] Although the correlation coefficients for *PC* index in Figure 2 are on average lower and have more spread than those for *PM* index, Figure 2 clearly demonstrates the same effect as shown in Figure 1. For northern winter months, the *AL* index well correlate with the *PCn* and *PMn* indices from the northern hemisphere and worse correlated with *PCs* and *PMs* indices from southern hemisphere, while for southern winter months the situation is opposite: the correlation of *AL* index with northern *PCn* and *PMn* indices appears much worse than that with southern *PCs* and *PMs* indices.

[13] The same seasonal effect in the correlation between the *AL* index and magnetic disturbances in the two polar regions was also observed for other years considered. In all cases, the *AL* index in northern winter shows a good correlation with geomagnetic activity in the nearby (northern) polar cap while in southern winter it shows the better correlation with geomagnetic activity in the opposite, remote polar cap. The counter-phase seasonal correlation between the *AL* index and geomagnetic disturbances in two polar caps is both clear and highly reproducible.

4. Discussion and Conclusion

[14] Thus, while using the data for four years (1990–1991 and 1997–1998) when geomagnetic activity indices were available in both hemispheres, we found that substorm activity in the northern hemisphere, as measured by *AL* index, shows an interesting and unexpected correlation with magnetic disturbances in two polar caps. While in winter in the northern hemisphere, the *AL* index correlates better with geomagnetic activity indices in the northern polar cap, in summer the result is just the opposite: the *AL* index correlates much better with geomagnetic activity indices in the opposite, southern polar cap. Why substorm activity as measured in the northern hemisphere in summer months correlates better with geomagnetic activity in the opposite, distant polar cap than with geomagnetic activity in the nearby polar cap is an interesting and important question. A significant decrease in the correlation between *AL* index and *PC* indices in two hemispheres during local summer months (northern summer for northern *PC* and southern summer for southern *PC*) was earlier reported by *Vennerstrøm et al.* [1991, Figure 4], which is consistent with our results. Regrettably, the correlation coefficients for northern and southern *PC* indices, shown by *Vennerstrøm et al.* [1991, Figure 4], are related to different time intervals (*PCs* index was not available all years); comparing the values of these correlation coefficients, therefore, is not correct.

[15] The puzzling behavior in the correlation of *AL* index and magnetic disturbances in two polar caps may be caused by an effect of the field-aligned interhemispheric currents (IHC) flowing from the summer high-latitude ionosphere and closing through the ionosphere in the opposite auroral zone. The IHC appear as a result of different conductivity in conjugate regions of northern and southern ionospheres. The important role of IHC in mid-latitude ionosphere is well known, however, their role in high-latitude ionosphere is not well investigated. For references, we mention the papers by *Benkevich et al.* [2000], *Benkevich and Lyatsky* [2000], *Yamashita and Iyemori* [2002], and *Hurtaud et al.* [2007] and references therein, where the role of the IHC is discussed. An interesting feature of these interhemispheric currents in the high-latitude ionosphere is that they are directed opposite to the substorm field-aligned currents in the summer hemisphere but along the substorm field-aligned currents in the winter hemisphere. This reduces the total field-aligned currents as well as their effect on magnetic disturbances in the summer hemisphere but increases the total currents and their effect on magnetic disturbances in winter hemisphere, which explains the experimental result obtained in this study.

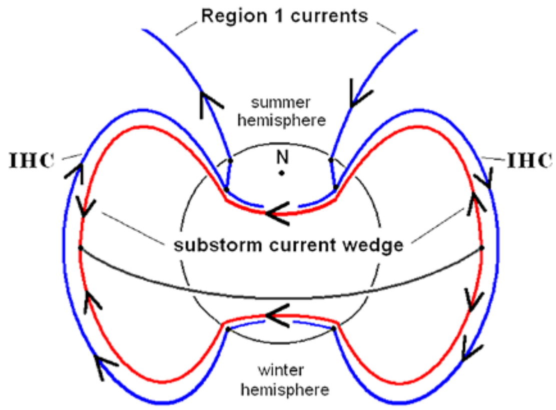

Figure 3. Schematical view of currents during northern summer. The currents of substorm current wedge are shown in blue, the Region 1 currents are shown in red. Interhemispheric field-aligned currents (IHC) are branched from the Region 1 currents, flow along the magnetic field to opposite (winter) hemisphere and close the ionospheric currents in the southern auroral zone.

[16] Figure 3 shows schematically the currents during the northern summer. The currents of substorm current wedge are shown in red; the Region 1 currents, generated as a result of the interaction between the solar wind and the magnetosphere, are shown in blue. In summer hemisphere, the Region 1 currents are branched into the interhemispheric field-aligned currents (IHC) closing through the ionosphere in the opposite (winter) auroral zone.

[17] The effect of the interhemispheric currents in Figure 3 is consistent with the results of the present paper. The interhemispheric field-aligned currents are opposite to the field-aligned currents of substorm current wedge, and they reduce the total field-aligned currents in the summer hemisphere and their effect in the summer polar cap. In the opposite hemisphere, the IHC are flowing in the same direction as the substorm field-aligned currents, which increases the total field-aligned currents in the winter hemisphere and their effect in the winter polar cap.

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G. V. Khazanov and W. Lyatsky, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA.

S. Lyatskaya, Department of Physics, Alabama A&M University, 4900 Meridian Street, Normal, AL 35762, USA. (lyatsky@hotmail.com)